Mitigating Overhead Line Sags:
Key Measure to Boost Power System Reliability

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Excessive transmission line sag is one of the most prevalent causes for limiting the line ampacity and has reportedly resulted in numerous power system outages, particularly for line rating of 230kV and below. Thermal expansion of the conductor resulting from high ambient temperatures, low winds, and high line current can lead to excessive line sag. Increases in demand, especially on hot summer days, increases the likelihood of excessive sag and the associated reliability issues.

Utilities have traditionally implemented two classes of solutions to deal with this problem. The first class aims to limit conductor temperature rise by:

- Implementing operating measures to reduce power flow in the affected line;
- Reconductoring the affected line with a conductor of larger cross-section; and
- Building a new line "in parallel" with the affected line.

All these solutions deal with the root of the problem and, except for the first listed, they do not require constant monitoring and specific maintenance activities and costs. However, all come with a very high opportunity or actual costs.

The second class of solutions deals with the outward symptom of line sag:

- Raising tower to compensate for the excess sag;
- Adding intermediate towers at key line locations to increase ground clearances; and
- Managing objects underneath line spans such as vegetation management.

The first of these two measures is both expensive and can be impractical in areas where height of transmission towers can become the source of other complications. The latter measures are the most common approach to keeping lines clear of underlying objects.

However, each has its own limitations, including frequent and expensive monitoring and maintenance. Even the complete removal of all underlying objects will not resolve the harmful clearance problems created by excessive line sag.

SLiM: A New Approach

The newest device to mitigate line sag (hence commercially called the Sagging Line Mitigator or SLiM) deals directly with the cause of the line sag: line elongation due to rising conductor temperature. SLiM installs in series with the line and becomes shorter as the conductor temperature rises due to high current flow and ambient conditions.

SLiM maintains a nearly constant effective line length and sag within the span as conductor temperature rises. Its benefits include low cost, passivity and practically zero maintenance.

The concept behind SLiM (i.e. shortening the line length during high temperature conditions by use of special materials) has been around for a number of years. However, earlier embodiments proved impractical and unreliable because of limited range of operation and high potential for fatigue failure.

The SLiM design and embodiment was invented and prototyped by Material Integrity Solution of Berkeley, CA, with partial funding from the California Energy Commission (CEC) and the Electric Power Research Institute (EPRI). After going through extensive functionality and reliability testing at a utility and at independent laboratories, SLiM is currently going through a final demonstration stage at San Diego Gas & Electric.

As conductor temperature rises, the "Actuator" within the SLiM device, which consists of a "Shaped Memory Alloy ", contracts. This action requires the Actuator to heat up as the conductor's temperature rises due to current flow and ambient conditions. For this purpose, some or all the conductor current is directed through the Actuator. Finally, the Lever in SLiM will amplify the Actuator's contraction and provide for an effective reduction in the length of the conductor within a span.

The pre-production model of the SLiM device was designed to "reduce" the conductor length by as much as eight (8) inches. This reduction in length translates into a large decrease in sag (magnitude depends on span configuration and conductor type). A reduction of about 4 feet in sag was achieved for a 500 ft tower span during the functionality testing at the Pacific Gas & Electric Company.

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As conductor temperature returns to normal, SLiM returns to its original shape, preventing excess tension in the line, and readying the device to respond to the next conductor temperature excursion.

By using a simple, passive, and reliable construction, SLiM has been designed to have a very long life and remain virtually maintenance-free. Its use of industry standard connectors allows for installation by linemen at any span. Since the device was designed to be installed similar to "splicing technique", it can be installed using live-line procedures. Its operation is also adjustable to match specific line and configuration requirements.

Functionality Testing

The SLiM device went through full scale functionality testing at the PG&E facilities in July 2002. The tests were conducted on two 500' spans (a control-span and a test-span with one SLiM device) of 795kcmil 54/7 ACSR (condor) conductor operating at 5000lbs and 90oF. Conductors were heated by a current of up to 1200A. The sag differential between the two conductors at a maximum temperature of 210oF was ~4'. Results from these tests have shown that SLiM can eliminate excess sag problems.

Reliability Rating and Simulation Studies

In addition to the functionality testing at PG&E, the following series of reliability tests and simulation studies were performed on SLiM at various facilities including Kinectrics Lab (formerly Hydro Research Division) and IREQ (Hydro Quebec Institute of Research):

- Electrical connection testing
- Corrosion and fatigue
- Short circuit testing
- Mechanical stress testing
- Electromagnetic transient (EMTP) studies
- Dynamic (vibration) studies using Finite Element Techniques

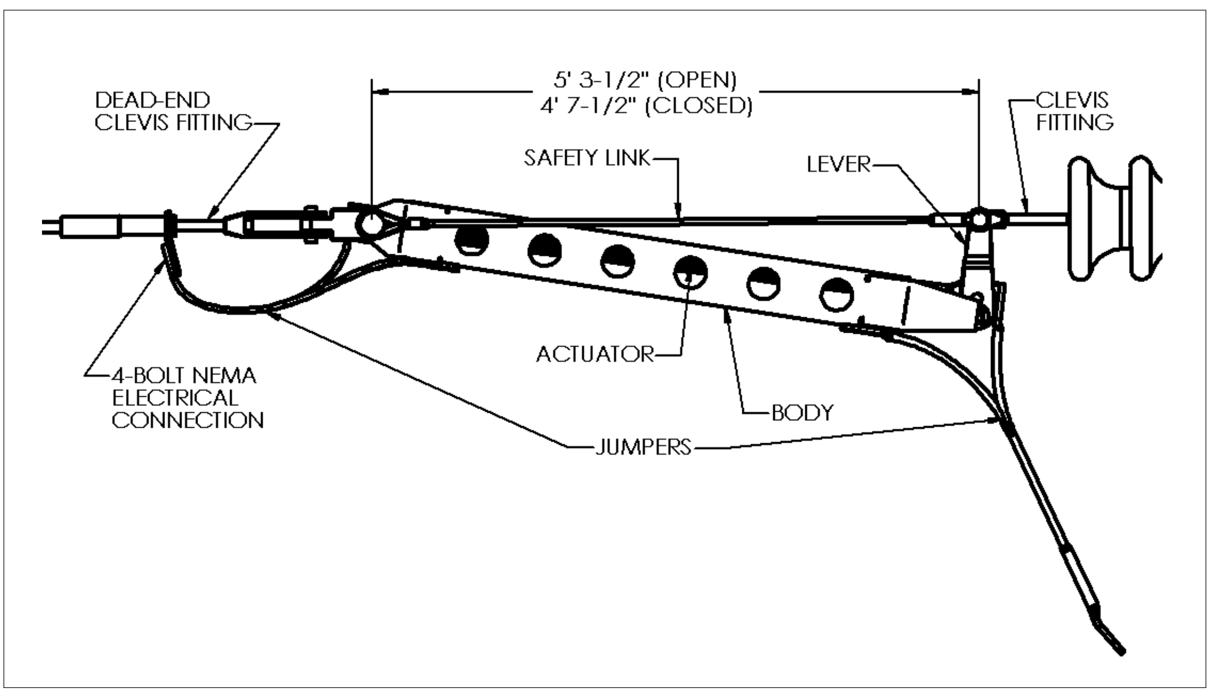
These tests/studies have all shown that the device is reliable for its intended applications and will have no negative effects on the line's electrical or mechanical performance.

Possible SLiM Applications

A high-voltage system contingency situation (i.e., outages on one or more lines) can cause loading on nearby lower voltage lines that exceed their established thermal limits. These limits are normally established to maintain conductor-to-ground clearances. Thus, the action of SLiM, which mitigates the usual sag caused by high temperature operation, can allow for safe line operation during the contingency situation. Line capacity is increased by allowing operation beyond conventional thermal limits. And, expensive line modification projects to address such contingency operation may not be averted or delayed.

Many older lines were constructed to 120°F maximum conductor temperature operation. Studies have shown that SLiM can enable operation of such lines at a conductor temperature exceeding 200°F without compromise of line clearances, tensions or integrity. This can represent a multi-fold increase of rated line capacity.

System planning may project that certain lines will become overloaded as local growth increases demand. In this instance SLiM can delay the need for either a new line or considerable line modifications while the anticipated load materializes.

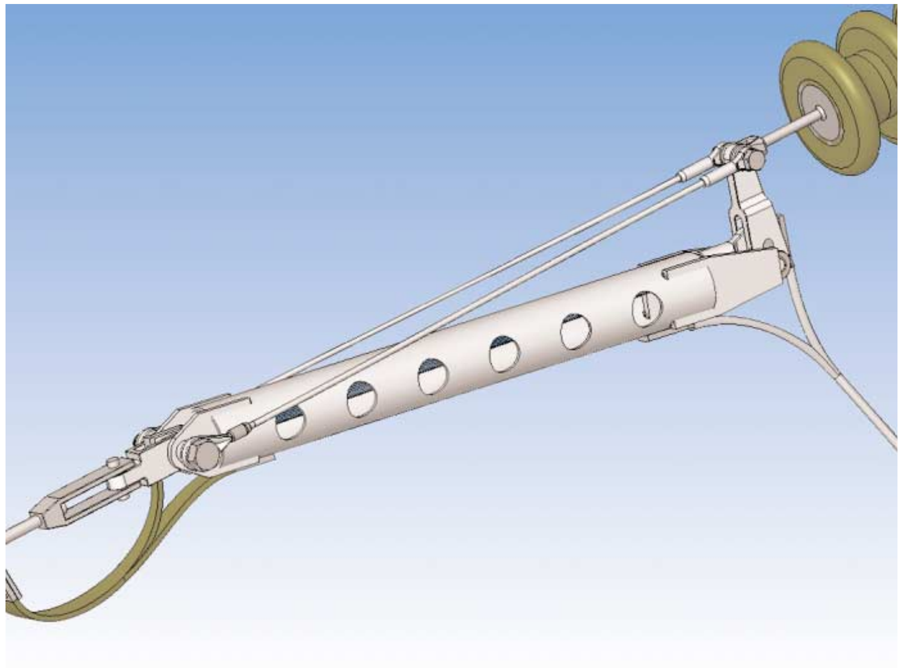


SLiM Schematic.

Demonstration

Under the sponsorship of EPRI and in Tailor Collaboration with several participating utilities (British Columbia Hydro, Consolidated Edison, Pacific Gas & Electric, San Diego Gas & Electric Company, Southern California Edison, Public Service of New Mexico, Northeast Utilities and National Grid) SLiM's performance will be demonstrated on up to three operating transmission lines. The number of demonstrations will depend on the number of project funding utilities.

The project is intended to provide participating utilities with first-hand information on the operational performance of this new kind of line hardware device. The demonstration is designed for operation during one "hot" season. The length of the trial can be extended, if necessary, with cooperation of the host utilities.



SLiM Device.

The project will compile practical "engineering-type" information to aid utilities in designing, specifying, installing, inspecting, and maintaining these devices. The results of this project will position participating utilities as informed buyers and users of this new technology.

The project will answer such questions as:

- How is SLiM best applied on a line with high temperature sag problems?
- What are relevant design parameters for SLiM application and use?
- Are there differences between real line installations and prior tests of SLiM?
- What, if any, additional special installation considerations are necessary for SLiM?
- Are there limits to SLiM applications?
- What are installation, operation, and lifetime costs of using SLiM?
- Are special inspection or maintenance methods necessary?

The project was initiated in June 2003 and is expected to be completed by March 2005. The first demonstration will take place at SDG&E and is expected to complete by the end of 2004. ❑

Comment on this article.

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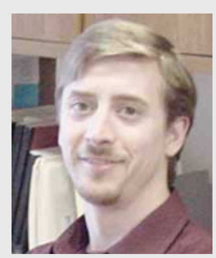
about the authors

Dariush Shirmohammadi is the Executive Advisor to Material Integrity Solutions, Inc. of Berkeley, CA. He is also the Chief Consultant with Shir Power Engineering Consultants, Inc. of Beverly Hills, CA, where he offers business and technical consulting on designing and implementing electricity markets and on improving the reliability of the electric power systems. His 27-year tenure in power industry includes positions as Senior Vice President and Head of Americas Energy Markets with OM, a Managing Consultant with PA Consulting Group, the Director of Emerging Energy Market Services with Perot Systems Corporation, and the Director of Energy Systems Automation Group with Pacific Gas & Electric Company. Dariush has authored numerous technical papers and has lectured in academic, industrial and regulatory forums around the world. Dariush has a Ph.D. in Electric Power Engineering from the University of Toronto and is a registered professional engineer. He is also a fellow of IEEE.



David Kopperdahl is the Lead Engineer for Material Integrity Solutions, Inc. and has over 7 years of experience in the design, analysis, and product development of mechanical and electromechanical systems as well as orthopedic biomechanics. His key strengths are in mechanism design, finite element modeling, stress analysis, kinematics analysis, material testing, and machining/fabrication processes. David received his Ph.D. in Mechanical Engineering from the University of California, Berkeley, with minor in Material Science. He has M.S.M.E. from UC, Berkeley and B.S.M.E. from UC, Davis. He has numerous technical publications.